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H1C 208 213 239 23X 23Y 260 26Y 28Y 30Y 351 35Y 367 368 36Y 370 392 394 39Y 410 425 480 482 48Y 490 498 500 502 522 523 527 52Y 532 534 538 560 56Y 585 611 622 627 62Y 634 63Y 661 66Y 713 714 73Y 741 744 74Y 761 76Y 770 77Y 782 783 785 78Y

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(54) SYSTEM FOR GENERATING LASER LIGHT OF THE THREE PRIMARY COLORS

(71) We, XEROX CORPORATION, of Rochester, New York 14603, United States of America, a Body Corporate organised under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a system for generating three modulated beams of laser light, the color of each beam corresponding to a different one of the three primary colors.

Systems of this type can be used for projecting color television pictures for forming color holograms and for a variety of other purposes. In the November/December, 1968, issue of Optical Spectra, pages 34 and 35, there is disclosed a system of this type comprising a krypton laser for generating a beam of red light and an argon laser for generating a beam of green light and a beam of blue light. In U.S. Patent 3,303,276 it is disclosed that a system of this type can be constructed by using certain combinations of semi-conductor lasers or certain combinations of gas lasers or certain combinations of ruby lasers. In the May 24, 1969, issue of Electronics Design 11, pages 52 through 54, there is disclosed a system of this type comprising a helium-neon laser for generating a beam of red light and an argon laser for generating a beam of green light and a beam of blue light. In addition, it is mentioned that a krypton laser can be used for generating beams of light of all three primary colors.

Even though beams of laser light of the three primary colors can be generated by using systems such as described above, the color quality of the three colors that has been obtained by using such systems has not been satisfactory. Improvement is therefore needed.

It is an object of this invention to provide a new and improved system for generating three beams of laser light, the color of each beam corresponding to a different one of the three primary colors.

It is another object of this invention to provide a new and improved system for generating three modulated beams of laser light, the color of each beam corresponding to a different one of the three primary colors.

According to the invention there is provided a system for generating three modulated beams of laser light, the colour of each beam corresponding to a different one of the three primary colours comprising:

(a) a first Nd:YAG laser adapted to emit a modulated beam of light at a wavelength of 0.6595 microns,
(b) a second Nd:YAG laser adapted to emit a modulated beam of light at a wavelength of 0.5300 microns, and
(c) a third Nd:YAG laser adapted to emit a modulated beam of light at a wavelength of 0.4390 microns.

An example of the invention will now be described with reference to the accompanying drawings in which

Figure 1 is a schematic view of a system constructed according to this invention,

Figure 2 is a standard chromaticity diagram with plots of the three primary colors generated by three different types of systems, one of the three systems being the system of this invention.

Referring to the drawings, there is shown in Figure 1 an example of a system constructed according to this invention.

The system includes three Nd:YAG lasers identified by reference numerals 20, 40 and 60.

Laser 20 operates at a wavelength of 1.319 microns and emits an amplitude modulated beam of red light at a wavelength of 0.6595 microns. Laser 40 operates at 1.06 microns and emits an amplitude modulated beam of green light at 0.5300 microns. Laser 60 operates at 1.319 microns and emits an amplitude modulated beam of blue light at 0.4390 microns.

Laser 20 includes a rod 21 of Nd:YAG having end surfaces 22 and 23 that are inclined at Brewster's angle. Pump energy is supplied to rod 21 from a suitable pumping source 24, such as a krypton lamp coupled to a d.c. source. Rod 21 is located inside an optical cavity defined by a pair of mirrors 25 and 26. Mirror 25 is designed so as to be about 100% reflective at a frequency of 1.319 microns and about 100% reflective at 0.6595 microns. Mirror 26 is designed so as to be about 100% reflective at 1.319 microns but at least partially and preferably about 100% transmissive at 0.6595 microns. Mirrors 25 and 26 may be multi-layer dielectric coatings formed on glass substrates. Laser 20 further includes a frequency doubler 27. As can be seen in Figure 1, the frequency doubler 27 is located inside the optical cavity adjacent the rod 21 and in optical alignment with the rod 21. Frequency doubler 27 comprises a non-linear electro-optic crystal such as barium-sodium-niobate or lithium niobate. The crystal is cut and oriented inside the optical cavity in such a way that it functions as a frequency doubler. The crystal is temperature tuned to the optimum temperature for frequency doubling by a heater 28. Electrodes 29 and 31 are formed on opposite sides of the crystal and are connected by leads 32 to a modulating signal source 33. The modulating signal source 33 is any source of variable voltage.

Laser 20 operates as follows. When sufficient pump energy is supplied to the rod 21 from the pumping source 24, laser light is emitted from the ends 22 and 23 of the rod 21 at 1.319 microns and passes through the frequency doubler 27 as it isreflected back and forth between mirrors 25 and 26 of the optical cavity. As the light passes through the frequency doubler 27, the frequency doubler 27 interacts with the light and causes light to be generated at 0.6595 microns (i.e. half the fundamental wavelength of 1.319 microns). As the amplitude of the signal supplied to the frequency doubler 27 from the modulating source is increased, the amplitude of the light generated by the frequency doubler 27 at 0.6595 microns is correspondingly decreased. Since mirrors 25 and 26 are both about 100% reflective at 1.319 microns, the light emitted by the rod 21 at a fundamental wavelength of 1.319 microns remains inside the optical cavity and is not coupled out. However, since mirror 26 is at least partly transmissive at 0.6595 microns, at least some of the light generated in the cavity at 0.6595 microns is coupled out. Thus the output of laser 20 is an amplitude modulated beam of red light at 0.65955 microns.

Additional information relating to the use of an electrically controlled non-linear electro-optic crystal inside the optical cavity of a laser for generating modulated frequency doubled light and the design of the optical cavity so as to allow only the frequency doubled light to be coupled out can be found in copending Application 25614/71 (Serial No.).

Laser 40 includes a rod 41 of Nd:YAG having Brewster's angle end surfaces 42 and 43, a pumping source 44, an optical cavity defined by a pair of mirrors 45 and 46, a frequency doubler 47, a heater 48 a pair of electrodes 49 and 51, leads 52 and a modulating signal source 53. Except for the mirrors 45 and 46, these elements of laser 40 are the same as the corresponding elements in laser 20. Mirror 45 is designed so as to be about 100% reflective at 1.06 microns and about 100% reflective at 0.5300 microns. Mirror 46 is designed so as to be about 100% reflective at 1.06 microns but at least partially and preferably about 100% transmissive at a frequency of 0.5300 microns.

Laser 40 operates in essentially the same manner as laser 20 but at an operating wavelength of 1.06 microns instead of at 1.319 microns due to the difference in design of the mirrors that form the optical cavity. Consequently, the light emerging from the ends of rod 41 is at 1.06 microns, the light generated by the frequency doubler 47 is at 0.5300 microns and the light that is coupled out of the optical cavity through mirror 46 is an amplitude modulated beam of green light at 0.5300 microns.

Laser 60 includes a rod 61 of Nd:YAG having Brewster's angle end surfaces 62 and 63, a pumping source 64, an optical cavity defined by a pair of mirrors 65 and 66, a frequency doubler 67, a heater 68, electrodes 69 and 71, leads 72 and a modulating signal source 73. Except for the mirrors 65 and 66, these elements of laser 60 are the same as the corresponding elements in laser 20. Mirror 65 is designed so as to be about 100% reflective at 1.319 microns, about 100% reflective at 0.6595 microns and about 100% reflective at 0.4390 microns. Mirror 66 is designed so as to be about 100% reflective at 1.319 microns, about 100% reflective at 0.6595 microns and at least partially and preferably 100% transmissive at 0.4390 microns. Laser 60 further includes a frequency mixer 74 for mixing the light emitted by the rod 61 at the fundamental

frequency with the light generated by the frequency doubler 67 at twice the fundamental operating frequency and produce thereby light at three times the fundamental operating frequency. Frequency mixer 74 is essentially a non-linear electro-optic crystal, such as barium-sodium-niobate or lithium niobate. The crystal is cut and oriented in the optical cavity so as to function as a frequency mixer and is temperature tuned to the optimum temperature for frequency mixing by a heater 75.

Laser 60 operates in a manner similar to laser 20. Light emerging from rod 61 at 1.319 microns passes through frequency doubler 67 wherein light at 0.6595 microns is generated. Light emitted by the rod 61 at 1.319 microns and the light generated by the frequency doubler 67 at 0.6595 microns passes through frequency mixer 74 wherein light is generated at 0.4390 microns. As the amplitude of the voltage signal applied to the frequency doubler 67 from the modulating signal source 73 is increased, the amplitude of the light generated at 0.6595 microns and consequently the light generated at 0.4390 microns are correspondingly decreased. Since mirrors 64 and 65 are about 100% reflective at 1.319 microns and at 0.6595 microns the light that traverses the optical cavity at 1.319 microns and at 0.6595 microns remains inside the optical cavity. However, since mirror 65 is at least partially transmissive at 0.4390 microns, light emerging from crystal 74 at 0.4390 microns is coupled out of the optical cavity.

The system further includes a fully reflective mirror 81, a dichroic mirror 82 and a trichroic mirror 83 arranged so as to combine the different colored beams of light emerging from the three lasers into a single three colored beam of light. Mirror 81 is fully reflective in the red and is positioned to reflect the beam of red light emerging from laser 20 in the direction of mirror 82. Mirror 82 is fully transmissive in the red and fully reflective in the green and is arranged so as to combine the beam of red light reflected by mirror 81 and the beam of green light emerging from laser 40 into a single beam of red and green light. Mirror 83 is fully transmissive in the red and green and fully reflective in the blue and is arranged so as to combine the beam of red and green light emerging from mirror 82 and the beam of blue light emerging from laser 60 into a single beam of red, green and blue laser light.

Referring now to Figure 2, there is shown a standard chromaticity diagram 90 with three plots 91, 92 and 93. Plot 91 is a plot of the three primary colors obtained by using three Nd:YAG lasers constructed according to this invention. Plot 92 is a plot of the three primary colors obtained by using a krypton laser for generating a beam of red light and an argon laser for obtaining a beam of green light and a beam of blue light. Plot 93 is a plot of three primary colors obtained in present day, commercial color television systems by using electron beam guns and a screen having different primary colored phosphor dots.

As can be seen, the colors obtained by using Nd:YAG lasers are superior to the colors obtained by using the other systems. This is especially true in the blue region which hitherto has been one of the most difficult regions to obtain good color reproduction.

WHAT WE CLAIM IS:—

1. A system for generating three modulated beams of laser light, the colour of each beam corresponding to a different one of the three primary colours comprising:
   (a) a first Nd:YAG laser adapted to emit a modulated beam of light at a wavelength of 0.6595 microns,
   (b) a second Nd:YAG laser adapted to emit a modulated beam of light at a wavelength of 0.5300 microns, and
   (c) a third Nd:YAG laser adapted to emit a modulated beam of light at a wavelength of 0.4390 microns.

2. The system as claimed in claim 1 further including means for combining the three modulated beams of light emitted by the three Nd:YAG lasers into a single modulated beam of light.

3. The system as claimed in claim 1 or claim 2 wherein the first Nd:YAG laser is designed to operate at a wavelength of 1.319 microns and includes a frequency doubler for generating the light at a wavelength of 0.6595 microns, the second Nd:YAG laser is constructed to operate at a wavelength of 1.06 microns and includes a frequency doubler for generating the light at a wavelength of 0.5300 microns and the third Nd:YAG laser is constructed to operate at a wavelength of 1.319 microns and includes a frequency doubler and a frequency mixer for generating the light at a wavelength of 0.4390 microns.

4. The system as claimed in claim 1 or claim 2 wherein the first Nd:YAG laser comprises an optical cavity resonant at a wavelength of 1.319 microns and constructed so as to allow light to be coupled out at a wavelength of 0.6595 microns but not at a wavelength of 1.319 microns, a rod of Nd:YAG disposed in the optical cavity, a pumping source for pumping the rod, a frequency doubling crystal disposed in the optical cavity, and a modulating signal source connected to the frequency doubling crystal.

5. A system as claimed in claim 4

wherein the optical cavity comprises a pair of mirrors, one of the mirrors being about 100% reflective at a wavelength of 1.319 microns and about 100% reflective at a wavelength of 0.6595 microns, the other mirror being about 100% reflective at a wavelength of 1.319 microns and at least partially transmissive at a wavelength of 0.6595 microns.

6. A system as claimed in any one of the preceding claims wherein the second laser comprises:

(a) a pair of mirrors defining an optical cavity, one of the mirrors being about 100% reflective at a wavelength of 1.06 microns and about 100% reflective at a wavelength of 0.5300 microns, the other mirror being about 100% reflective at a wavelength of 1.06 microns and at least partially transmissive at a wavelength of 0.5300 microns.

(b) a rod of Nd:YAG disposed in the optical cavity,

(c) a pumping source for pumping the rod so as to cause the rod to lase and emit thereby light at a wavelength of 1.06 microns,

(d) a frequency doubler disposed in the optical cavity for interacting with the light emitted by the rod at a wavelength of 1.06 microns and generating thereby light at a wavelength of 0.5300 microns, and

(e) a modulating signal source connected to the frequency doubler for varying the amplitude of the light generated by the frequency doubler.

7. A system as claimed in any one of the preceding claims wherein the third laser comprises:

(a) a pair of mirrors defining on optical cavity, one of the mirrors being about 100% reflective at a wavelength of 1.319 microns, about 100% reflective at a wavelength of 0.6595 microns and about 100% reflective at a wavelength of 0.4390 microns, the other mirror being about 100% reflective at a wavelength of 1.319 microns, about 100% reflective at a wavelength of 0.6595 microns, and at least partially transmissive at 0.4390 microns,

(b) a rod of Nd:YAG disposed in the cavity,

(c) a pumping source for pumping the rod, so as to cause the rod to lase and emit thereby light at a wavelength of 1.319 microns,

(d) a frequency doubler disposed in the cavity for generating light at a wavelength of 0.6595 microns.

(e) a modulating signal source connected to the frequency doubler for varying the amplitude of the light generated by the frequency doubler, and

(f) a frequency mixer disposed in the cavity for mixing the light at a wavelength of 1.319 microns and the light at a wavelength of 0.6595 microns so as to produce thereby light at a wavelength of 0.4390 microns.

8. A laser beam generating system substantially as herein described with reference to and as illustrated in the accompanying drawings.

For the Applicants:
A. POOLE & CO.,
Chartered Patent Agents,
19 Devonshire Street,
London, W1N 2BJ.

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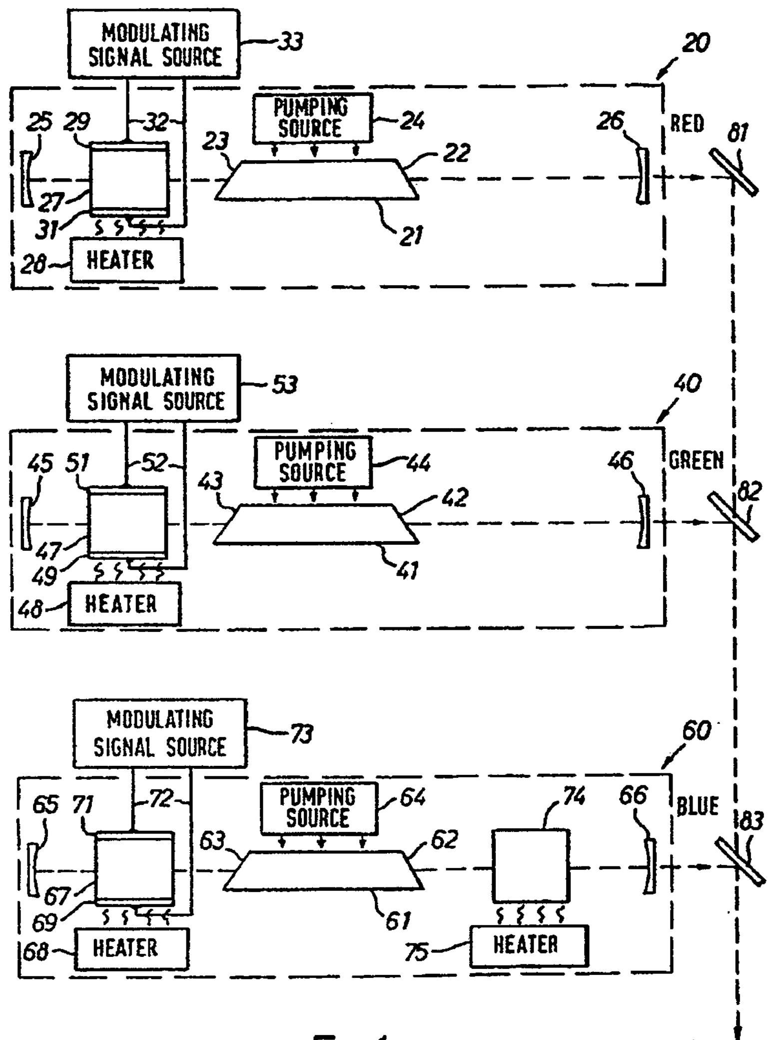
MODULATING SIGNAL SOURCE
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MODULATING SIGNAL SOURCE
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FIG.1

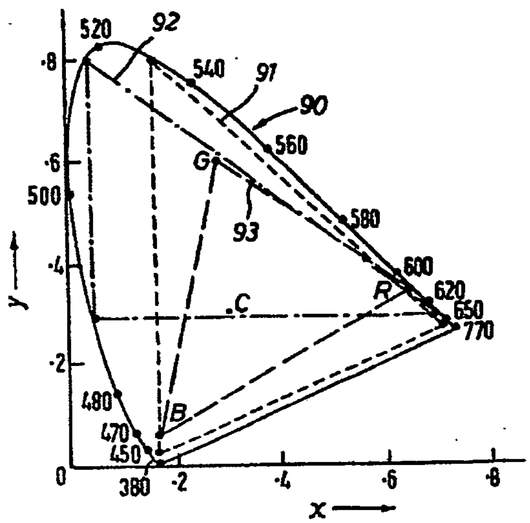

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FIG. 2